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<b>14. ABSTRACT</b> <p>Since the end of the Cold War, a considerable cause for concern has been the potential loss of accountability of nuclear/chemical weapons, missiles, and associated technologies and materials in former Soviet states. This state of affairs has induced a reevaluation of the strategic, operational, and tactical postures of the armed forces to deal with the broad array of threats to our security. Of these threats, the possibility of a large-scale conventional bomb/missile, nuclear, or chemical/biological attack on the homeland, our national interests abroad, or deployed forces rank high. Ultimately, this is because 1) such weapons have the potential to inflict mass destruction on several levels; 2) obtaining these weapons, or the materials necessary to fabricate them, has become relatively easy; and 3) the asymmetric nature and radical idealism of the enemies who oppose our interests increases the level of uncertainty.</p> <p>A critical aspect of these threats is the manner in which our enemies could employ them. One that interests the Army's Aviation &amp; Missile Research, Development, and Engineering Center (AMRDEC) is the use of ballistic missiles as a delivery platform. Accordingly, this organization has expanded its research of ballistic missile defense to include analysis of emerging technologies as viable military options. Pursuant to that end, AMRDEC chartered the Department of Systems Engineering at West Point to conduct a feasibility study of the use of SCRAMJET and other kinetic energy-based technologies for military purposes, with a particular emphasis on missile defense.</p> <p>Given that the effectiveness of any anti-ballistic missile (ABM) system will heavily depend on time, the intrinsic question any alternative must address is how much time do we have to intercept an incoming missile? It is clear that any system developed must minimize the time required to defeat the missile threat. Accordingly, we evaluated several employment alternatives which included land, sea, and air based options. In this paper, we focus on the latter alternative, specifically addressing the use of loiter aircraft as a capability added to anti-ballistic missile defense systems.</p>					
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***A Preliminary Analysis of Loitering Aircraft as a Capability Added  
to Anti-Ballistic Missile Systems  
(Unclassified)***

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**Abstract**

Since the end of the Cold War, a considerable cause for concern has been the potential loss of accountability of nuclear/chemical weapons, missiles, and associated technologies and materials in former Soviet states. This state of affairs has induced a reevaluation of the strategic, operational, and tactical postures of the armed forces to deal with the broad array of threats to our security. Of these threats, the possibility of a large-scale conventional bomb/missile, nuclear, or chemical/biological attack on the homeland, our national interests abroad, or deployed forces rank high. Ultimately, this is because 1) such weapons have the potential to inflict mass destruction on several levels; 2) obtaining these weapons, or the materials necessary to fabricate them, has become relatively easy; and 3) the asymmetric nature and radical idealism of the enemies who oppose our interests increases the level of uncertainty.

A critical aspect of these threats is the manner in which our enemies could employ them. One that interests the Army's Aviation & Missile Research, Development, and Engineering Center (AMRDEC) is the use of ballistic missiles as a delivery platform. Accordingly, this organization has expanded its research of ballistic missile defense to include analysis of emerging technologies as viable military options. Pursuant to that end, AMRDEC chartered the Department of Systems Engineering at West Point to conduct a feasibility study of the use of SCRAMJET and other kinetic energy-based technologies for military purposes, with a particular emphasis on missile defense.

Given that the effectiveness of any anti-ballistic missile (ABM) system will heavily depend on time, the intrinsic question any alternative must address is how much time do we have to intercept an incoming missile? It is clear that any system developed must minimize the time required to defeat the missile threat. Accordingly, we evaluated

several employment alternatives which included land, sea, and air based options. In this paper, we focus on the latter alternative, specifically addressing the use of loiter aircraft as a capability added to anti-ballistic missile defense systems.

## 1. Background

Throughout the Cold War era, the possibility of nuclear war with the Soviet Union posed the greatest threat to the United States. While the concept of “mutually assured destruction” served as the primary source of deterrence between the two superpowers, many in the U.S. felt that this, in and of itself, was inadequate, which sparked research into the area of ballistic missile defense. On March 23, 1983, President Reagan announced the Strategic Defense Initiative (SDI). At that time, this program “envisioned nearly perfect defenses against very large missile attacks, which would require highly capable space-based intercept systems” (Pike, 2005).

With the end of the cold war, the perceived need for a missile defense system fell from the spotlight, as attention shifted from the threat of a large-scale nuclear exchange to the conventional aspects of low-intensity conflicts, support and stability operations, and peace-keeping/peace-enforcement operations. However, the emergence of asymmetric threats in the form of terrorist organizations in the years since the Soviet Union’s collapse has generated new concerns for our national security. In particular, the segmentation of the Soviet Union into the former satellite states has created international concern about the status and accountability of the former Soviet nuclear arsenals that existed in these states. Given the financial resources and clandestine operations of today’s global terrorist network, there exists a real possibility that one of these organizations could acquire access to these unaccounted weapons and employ them to further their cause.

The September 11<sup>th</sup> attacks against the United States highlighted our vulnerability to the asymmetric tactics and determination of today’s threats. Since then, we have determined to engage the global terrorist threat on ground of our choosing, beyond our borders. However, a question of singular importance remains: what happens if one of these groups obtains a weapon of mass destruction and how do we defend against it? In answering that question, the Department of Defense has reinvigorated research efforts aimed at developing missile defense systems. According to Defense Secretary Donald Rumsfeld,

*We have forces in Europe, we have them in the Gulf, we have them in Asia... we also have friends and allies. It’s important that we be able as a country to persuade the rest of the world that it’s not in their interest to have ballistic missiles. [Having a credible missile defense] would deter people from thinking that ballistic missiles are the weapon of choice to intimidate the United States and its friends and allies (Garamone, 2005).*

In short, our need for an anti-ballistic missile effort is as important as ever as weapons of mass destruction proliferate and the means to deliver them (specifically missiles) become more widely available.

## 2. Project Impetus

As it stands, the Army is the DoD-proponent for land-based missile defense systems. Accordingly, it has dedicated various organizations and research efforts to

developing systems to meet that responsibility. One such organization is the Army's Aviation and Missile Research, Development, and Engineering Center (AMRDEC), whose mission is to "plan, manage and conduct research, exploratory and advanced development, and provide one-stop life cycle engineering, technical, and scientific support for aviation and missile weapon systems and their support systems, UAV platforms, robotic ground vehicles, and all other assigned systems, programs and projects"(AMRDEC, 2005). In the last few years, there have been a number of successful tests of various types of kinetic energy (KE) projectiles, including hypersonic vehicles powered by supersonic-combustion ramjets (scramjets) (David, 2004). These have led organizations like AMRDEC to wonder if such vehicles could offer benefits in an anti-ballistic missile (ABM) role. Accordingly, AMRDEC commissioned the analytical efforts of the Department of Systems Engineering at the United States Military Academy to explore the suitability and feasibility of such KE technologies as capability added to ABM systems.

### **3. The Problem**

There are two key considerations in such a use of scramjet technology. First, the scramjet works best in a relatively thin layer of the earth's atmosphere at an altitude of approximately 90,000 feet. This is not to say that the projectile will not work below this altitude, but rather that it must attain this approximate altitude to achieve hypersonic speeds. It is at this altitude that the hydrogen-fueled engine interacts with the oxygen resulting in hypersonic speeds up to mach 9.6 or nearly 7,000 mph. The second consideration stems directly from the first: unless released directly into that portion of the atmosphere, the projectile will require some form of boost phase to get it there. These considerations led us to investigate the potential benefit of launching a scramjet missile or other projectile with a kinetic energy (KE) kill mechanism from a high-altitude aircraft loitering in the same region as the missile launch site. The loitering aircraft could be manned or unmanned, and of any type from fighter jet to dirigible. The concept is similar to that of the Air Force's Airborne Laser, which is designed to destroy missiles with a laser mounted in a loitering converted airliner (Butler, 2005).

To assess the viability and usefulness of this option, we conducted a capability/value-added analysis by analyzing how much time is available to intercept an incoming missile and whether we could achieve a low total time to intercept. Consider a hypothetical scenario involving the launch of a theater ballistic missile (TBM) with multiple independent warheads against a US target. Such missiles realize three distinct phases: 1) the Boost phase, 2) the Midcourse phase, and 3) the Terminal phase. Upon launch, a missile enters the boost phase, during which it accelerates until reaching terminal velocity. At this point, it transitions to the midcourse phase, which ends when the missile reaches its apogee. Upon reaching its apogee, the missile will "MIRV," or dispense the multiple independently-targetable re-entry vehicles or warheads against various targets, which begins the terminal phase of the missile. "While a MIRVed attacking missile can have multiple (3-12 on various US missiles) warheads, interceptors can only have one warhead per missile. Thus, in both a military and practical sense, MIRVs render ABM systems less effective" (Wikipedia, 2005).

Obviously, the mission requirement is to destroy the ballistic missile before it can MIRV or reach its apogee. A loftier goal would be to achieve such an intercept even

earlier, during the boost phase. According to the Missile Defense Agency, “intercepting a missile in its boost phase is the ideal solution..., since destroying a missile during this phase of flight precludes the deployment of any countermeasures, and also prevents the missile warhead from attaining the velocity necessary to reach its intended target” (Missile Defense Agency, 2004). The following table reflects some of the key parameters of typical ballistic missiles (Powell & Hass, 2005).

		Ballistic Missile Class			
		100 km	500 km	1000 km	3000 km
Boost Phase	Avg Acceleration (ft/s <sup>2</sup> )	132.88	183.07	177.60	172.45
	End-of-Boost Altitude (ft)	38,590	78,330	131,113	300,411
Midcourse Phase	Apogee (ft)	121,651	466,330	892,109	2,355,302
	Speed at Apogee (ft/s)	1,859	4,798	6,792	11,219
	Time to Apogee (s)	95	194	275	510

**Table 1. Ballistic missile parameters by class.**

As the table reflects, any system designed to intercept an incoming missile before it MIRVs must be able to do so within a few seconds to a few minutes of its launch. Although intercepting a missile while it is fighting against the earth’s gravity is ideal, it is not without significant challenges to the defender. Foremost, the boost phase covers a relatively short time window, which requires that sensors detect and relay the information about the missile to the interceptor platform very quickly. Second, common sense tells us that, for any ground-launched defense, the interceptor projectile must either be very close to the actual launch location or be exceptionally fast to overtake the accelerating missile (Missile Defense Agency, 2005). Even in the latter case, the natural delay in responding to a missile launch makes a ground-based intercept very difficult at best. For the purposes of our analysis, we sought to achieve intercept solutions prior to the end of the midcourse phase.

## **4. Methodology**

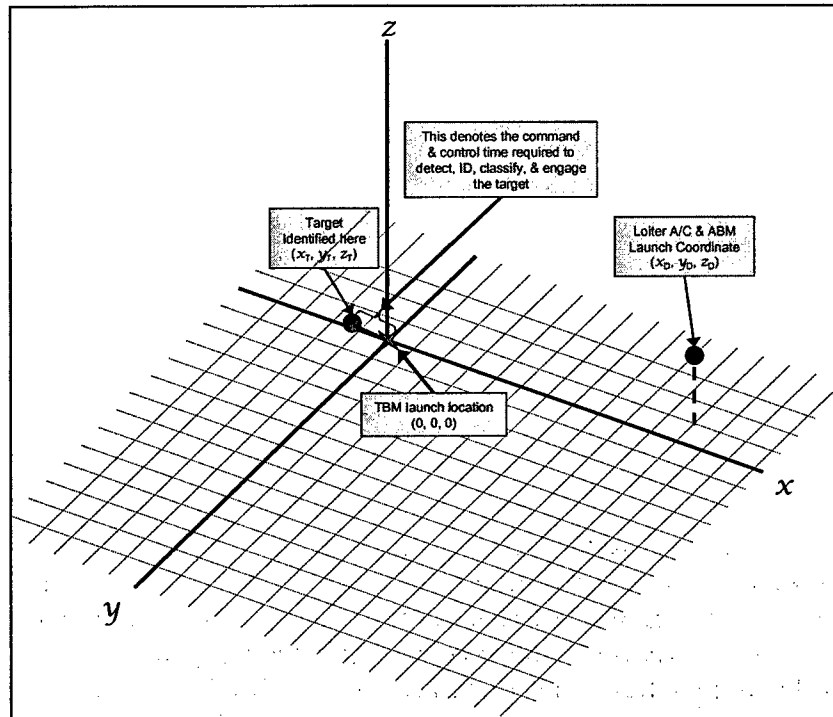
### **4.1 Overview**

In exploring the usefulness of using a loitering aircraft as a launch platform, we hypothesized that launching from some point above the ground would yield an increase in the time available to identify, classify, and engage incoming targets, compared to a ground launch. To test our hypothesis, we developed a simple model using Euclidean geometry in three dimensions, focusing on such critical aspects as command and control (C2) time or the time required to detect, identify, classify, and engage a target; the actual intercept time; the target’s apogee; and the impacts of altitude on all of these.

### **4.2 The Model**

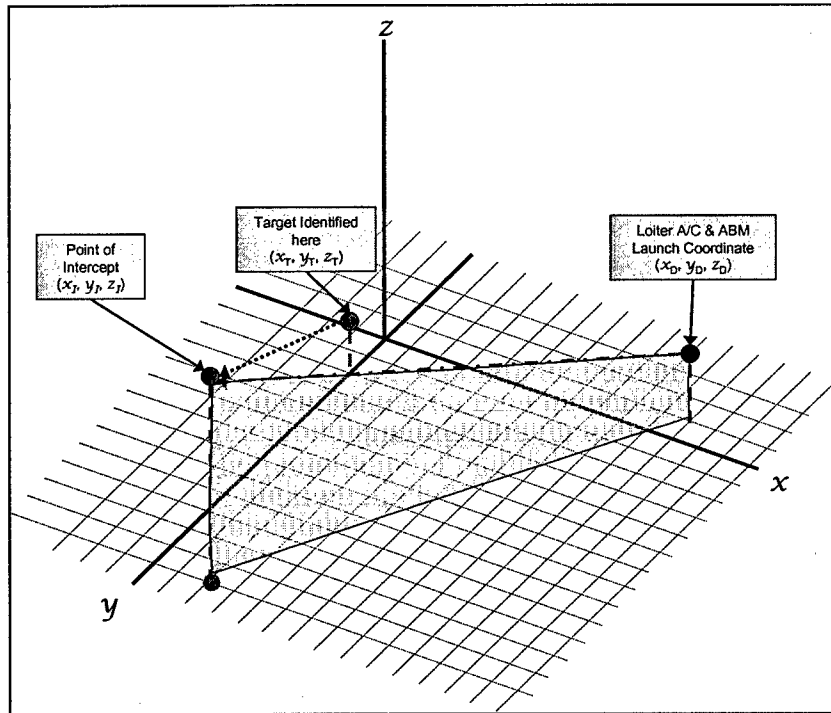
We began our modeling approach by developing a visualization of the intercept process, which we did in a three-dimensional plane. The following figures depict this visualization. Figure 1 shows both the target missile and the defender are located within

the  $(x, y, z)$  plane, which implies that the launch can occur from land, sea, or air. We started with a point of origin for both the target ballistic missile (a 500 km class missile for the purposes of experimentation) and the loitering aircraft (ABM launch platform). The model assumes that the target originates at the origin  $(0, 0, 0)$ , which then enables us to ascertain the location of the ABM launch platform relative to the target.



**Figure 1. Three dimensional graphic depicting the ballistic missile and the ABM launch platform in relation to each other.**

As Figure 2 reflects, once the defender has identified the target and computed an intercept solution, it launches the interceptor. We assume that both the attacker and defender are accelerating at the time of launch decision and that each continues to accelerate for a period of 20 seconds whereby they achieve terminal velocity. In reality, the acceleration is a nonlinear function of time, whereby the missile's acceleration actually fluctuates up and down during the boost phase. However, since the deviations are small relatively small, we can model the acceleration as independent of time. While our assumption renders the analysis calculation of time of intercept as an approximation, it will suffice for purposes of demonstrating the utility of an air-based interceptor launch. The actual variation in time will be minimal as one can show that the optimal policy for defender and attacker is to accelerate as fast as possible. Furthermore, in such an attack during powered ascent, a ballistic missile would not be able to maneuver radically to evade. At the current time these missiles can only maneuver for the purpose of avoiding detection by finding routes that go through sensor free geography. For these reasons, we disallow maneuver for the purpose of evasion for a TBM.



**Figure 2. Graphical depiction of an intercept solution in three-dimensional space.**

The solution principle for finding the time from ABM launch to intercept is that at intercept the coordinates of the defender and attacker are the same. We assume at the time of launch decision that we know the initial coordinates of the target missile, its velocity vector in three dimensions, its acceleration vector, and the time required to achieve terminal velocity. For the interceptor we must determine the velocity vector and the time of intercept. The latter must also account for the inherent command and control time associated with a launch as well as the interceptor's own acceleration window prior to achieving terminal velocity.

Our knowledge and assumptions about the physics of the target allow us to model this problem by creating a unit vector that will point in the final direction of the optimal intercept path. We denote this vector by

$$u' = (x, y, z), \text{ where } x^2 + y^2 + z^2 = 1.$$

This constraint, which we shall call the unit sphere constraint, is a simple but important feature in our methodology. By providing a vector with a magnitude equal to 1, the constraint alleviates the need to determine other variables, which further simplifies the calculations. In particular, this decomposes the magnitude of the defender's velocity into proportional magnitudes in the x, y, and z directions. Table 2 below summarizes the modeling parameters and variables we used. In the definitions, we denote the parameters of the target missile and the defender with a subscript "T" and "D" respectively. We use a subscript to denote directions x, y, and z; time is denoted by  $t$ .

Parameter/Variable	Definition
$t$	Time of intercept (elapsed time between ABM launch and intercept); this is assumed to be greater than the command and control time, the acceleration windows of both the target and the interceptor. This is not a general case.
$(0, 0, 0)$	Launch coordinates of the target
$(x_{IO}, y_{IO}, z_{IO})$	Launch coordinates of the interceptor (ABM)
$(x, y, z)$	Coordinates of unit vector in the direction of the interceptor's path
$t_{c2}$	Time of command and control. This is the time required to detect, identify, and classify the target; to acquire the threat path and acceleration components; and decide to engage or intercept.
$a_I$	Acceleration of the interceptor in the unit direction
$t_{aT}$	Total time the target accelerates from launch, at the end of which it achieves terminal velocity.
$t_{aI}$	Total time the interceptor accelerates, at the end of which it achieves terminal velocity. Acceleration due to gravity is ignored, although it can be easily accounted for.

**Table 2. Modeling parameters and variables**

In addition to the unit sphere constraint above, we also have the following sets of equations:

1) The coordinates of the ABM (interceptor) at intercept:

$$x_{II} = x_{IO} + x[.5a_I t_{aI}^2 + (a_I t_{aI}(t - t_{c2}))]$$

$$y_{II} = y_{IO} + y[.5a_I t_{aI}^2 + (a_I t_{aI}(t - t_{c2}))]$$

$$z_{II} = z_{IO} + z[.5a_I t_{aI}^2 + (a_I t_{aI}(t - t_{c2}))]$$

2) The coordinates of the target at the time of launch decision:

$$(.5a_{Tx}(t_{c2})^2, .5a_{Ty}(t_{c2})^2, .5a_{Tz}(t_{c2})^2) = (x_{TO}, y_{TO}, z_{TO})$$

and 3) The coordinates of the target at the time of intercept:

$$x_{TI} = x_{TO} + .5a_{Tx}(t_{aT} - t_{c2})^2 + a_{Tx}t_{aT}(t - t_{aT})$$

$$y_{TI} = y_{TO} + .5a_{Ty}(t_{aT} - t_{c2})^2 + a_{Ty}t_{aT}(t - t_{aT})$$

$$z_{TI} = z_{TO} + .5a_{Tz}(t_{aT} - t_{c2})^2 + a_{Tz}t_{aT}(t - t_{aT})$$

It follows that an intercept occurs at the point where the coordinates of the target and interceptor are the same. We can therefore combine our sets of equations to the following system of equations:

$$x_{IO} + x[.5a_I t_{aI}^2 + (a_I t_{aI}(t - t_{c2}))] = x_{TO} + .5a_{Tx}(t_{aT} - t_{c2})^2 + a_{Tx}t_{aT}(t - t_{aT})$$

$$y_{IO} + y[.5a_I t_{aI}^2 + (a_I t_{aI}(t - t_{c2}))] = y_{TO} + .5a_{Ty}(t_{aT} - t_{c2})^2 + a_{Ty}t_{aT}(t - t_{aT})$$

$$z_{IO} + z[.5a_I t_{aI}^2 + (a_I t_{aI}(t - t_{c2}))] = z_{TO} + .5a_{Tz}(t_{aT} - t_{c2})^2 + a_{Tz}t_{aT}(t - t_{aT})$$



Note that the use of the unit vector implies that the acceleration of the interceptor in the x direction is

$$x * \text{acceleration in the direction of the unit vector}$$

and the velocity of the interceptor in the x direction is

$$x * \text{velocity in the direction of the unit vector}$$

Moreover, the unit vector modeling eliminates the need for directions for the interceptor's parameters because of the unit vector modeling. We can now solve these three equations and the unit sphere constraint equation simultaneously to obtain an intercept solution. Pursuant to this, we constructed a geometry-based spreadsheet model in MS Excel, using the Solver add-in to compute intercept solutions based on specified command and control times and launch altitudes. Figure 3 provides a screen-capture of our Excel-based model.

XTO	44382.244 ft		Original coordinates of target from zero position to detect based on acceleration vector
YTO	38834.4635 ft		
ZTO	83216.7075 ft		
VTX	2664.8 ft/s		velocities of target in the three directions
VTY	2331.7 ft/s		
VTZ	4996.5 ft/s		
XIO	60000		Original Coordinates of Launch Platform
YIO	20000		(z denotes the LAUNCH ALTITUDE)
ZIO	80000		
x	0.009585308		x,y,z are unit directions to be determined
y	0.702266331		
z	0.711848384		
Time, t	25.61275861 sec	58.92276 sec	time of intercept and total time (intercept time + C2 time)
X <sub>i</sub>	60448.95928 ft		COORDINATES OF INTERCEPTOR AT INTERCEPT
Y <sub>i</sub>	52892.94413 ft		(Z <sub>i</sub> denotes intercept altitude)
Z <sub>i</sub>	113341.751 ft		enforces Unit Sphere Constraint
Unit vector	0.999998001		time to achieve terminal velocity for interceptor
t <sub>Interceptor</sub>	20 sec		given acc OF INTERCEPTOR IN ITS LINE OF FLIGHT
ACC	150 ft/s <sup>2</sup>		terminal velocity OF INTERCEPTOR
VTERM	3000		acceleration of target in x direction
ATX	80		acceleration of target in y direction
ATY	70		acceleration of target in z direction
ATZ	150		time to achieve terminal velocity for target
t <sub>ATarget</sub>	-13.31 sec		vector acceleration of threat
	183.8477631 ft/s <sup>2</sup>		
X <sub>Ti</sub>	60448.90177		COORDINATES OF TARGET AT INTERCEPT
Y <sub>Ti</sub>	52892.78905		(Z <sub>i</sub> denotes intercept altitude)
Z <sub>Ti</sub>	113341.6908		
DEVX	0.057509709		
DEVY	0.155078635		
DEVZ	0.060147778		
AOBJ	0.030974505	Target Intercepted	OBJECTIVE FUNCTION (minimize to zero)
C2 Time	33.31		Time to detect, identify, classify, and engage target

Figure 3. Screen-capture of our Excel-based model.

As highlighted in the Excel model, we compute three measures of interest: the time required to intercept the missile (highlighted in blue), the intercept altitude (highlighted in yellow), and the total elapsed time from target launch to intercept (also highlighted in blue). These allow us to analyze the impacts of launching from higher altitudes and with various amounts of command and control time. Input values are the loiter altitude and the command and control time, both highlighted in green

The AOBJ cell (highlighted in magenta) encapsulates the objective function. The function, shown below, sums the squared deviations of the x, y, and z coordinates between the interceptor and the target, whereby the subscripts I-int and T-int denote the (x,y,z) intercept coordinates of the interceptor and target respectively.

$$\text{MINIMIZE } [(X_{I\text{-int}} - X_{T\text{-int}})^2 + (Y_{I\text{-int}} - Y_{T\text{-int}})^2 + (Z_{I\text{-int}} - Z_{T\text{-int}})^2]$$

The model seeks a solution to the system of equations that minimizes this function, i.e. that gives is a value as close to zero as possible. An exceptionally small value indicates an intercept solution, which also is reflected by the intercept coordinates for both the interceptor and the target being the same. We considered values greater than 0.1 km to represent failure to intercept. It is worth noting here that the C2 time is a critically important element in this analysis, as it involves virtually all of the variability and error associated with human factors. In general, the more time we have to exercise command and control, the better, as this will usually tend to mitigate identification, classification, and targeting errors.

### 4.3 Results and Analysis

We sought to demonstrate the utility of high-altitude ABM launches by first computing the measures based on a ground launch (whereby the altitude of the launch is 0 feet), and then re-computing at increased loiter aircraft altitudes, which we did in 10,000-foot increments from 10,000 to 60,000 feet. Between 60,000 and 120,000 feet, we increased these increments to 20,000 feet. At each altitude, we further examined the impacts of increasing the amount of command and control time available to the decision maker.

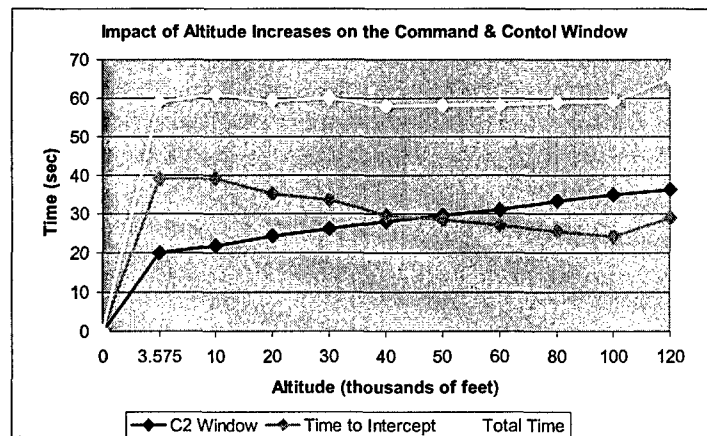
We ran our model at each altitude and determined the minimum and maximum command and control times available to achieve a feasible intercept solution. This established a "window of feasibility" outside of which an intercept would not be possible. Table 3 reflects the results of all of these runs. The (x, y, z) coordinates are included to show the location of the intercept relative to the ABM launch coordinates. Obviously, the z coordinate is the most important, as it indicates the intercept altitude relative to the ABM launch altitude.

Analyzing these results, we first found that, using our parameters for acceleration and time for both the target and the interceptor, we could not achieve an intercept at 0 seconds of C2 until we elevated the launch platform to 3,575 feet, which immediately indicated some criticality associated with an altitude-based launch. Thus, we could only begin to establish nonzero C2 windows at this altitude and higher.

	ABM Launch Coordinates (ft)					
	x	y	z			
	60,000	20,000	respective loiter altitude			
Loiter Altitude (ft)	C2 Time (seconds)	Time to Intercept	Total Time	Intercept Coordinates (ft)		
				x	y	z
0	0.00	No Solution Feasible				
3,575	0.00	38.968	39.068	46,190	40,416	86,606
	19.99	38.968	58.958	46,333	40,541	86,874
10,000	0.00	38.968	38.968	46,349	40,556	86,905
	21.87	39.048	60.918	49,749	43,530	93,279
20,000	0.00	39.049	39.049	46,478	40,669	87,147
	24.29	35.103	59.393	48,501	42,438	90,939
30,000	0.00	35.109	35.109	40,175	35,153	75,327
	26.32	33.629	59.949	51,115	44,725	95,840
40,000	0.00	23.054	23.054	20,886	18,275	39,161
	28.09	29.726	57.816	49,741	43,523	93,264
50,000	0.00	28.324	28.324	29,319	25,654	54,973
	29.66	28.573	58.233	52,638	46,059	98,697
60,000	0.00	31.529	31.529	34,446	30,140	64,586
	31.04	27.191	58.231	54,921	48,056	102,976
80,000	0.00	25.844	25.844	25,351	22,182	47,533
	33.31	25.613	58.923	60,449	52,893	113,342
100,000	0.00	28.293	28.293	29,269	25,610	54,879
	34.98	24.103	59.083	64,484	56,424	120,908
120,000	0.00	31.388	31.388	34,221	29,943	64,164
	36.26	28.856	65.116	77,336	67,669	145,005

**Table 3. Consolidated results reflecting the command and control windows, intercept times, and intercept coordinates at various altitudes.**

As the general results clearly show, increases in altitude yield corresponding increases in the amount of command and control time available, which is reflected by the difference between the minimum and maximum C2 times available at each altitude. This works in the following way: the total times reflect the entire "intercept window," which is a factor of time determined by the C2 time available and the time to intercept once the ABM has been launched. A comparison of the C2 times, intercept times, and total times yields the following graph.



**Figure 4. Graph of Time vs. Interceptor Launch Altitude**

As the graph clearly reflects, the time to intercept decreases as C2 time increases at each altitude. There are two main reasons for this. First, by waiting longer, the target is actually closing the gap between it and the ABM platform, thus shortening the distance and associated amount of time required to intercept. Second, at C2 time = 0, there is virtually no time to adjust targeting parameters to the actual situation, forcing an ABM launch with default parameters that have been pre-programmed. As such, the interceptor must make considerable course adjustments "on the fly" to achieve an intercept solution, which induces losses in acceleration, velocity, and time. A better course of action would be to utilize that time more effectively to minimize impacts on acceleration and velocity. Consequently, increases in the amount of C2 time available would enhance the decision and targeting process and would facilitate more precise intercept calculations, thereby alleviating the loss of acceleration and velocity due to course adjustments.

The column in Table 3 showing the z coordinate, or intercept altitude, also merits attention. Recall that the apogees for various classes of ballistic missiles range from 121,000 to over 2.2 million feet, which established the upper limit of feasibility for any intercept solution. Additional constraints presented by the physics of the target relative to the interceptor coupled with the amount of time available for command and control effectively decreases those upper limits, forcing intercepts to occur at much lower altitudes. As our results show, we achieve intercepts ranging between 39,000 and 145,000 feet, depending upon the launch altitude and the command and control time. Hence, increasing the launch altitude not only affords increased amounts of command and control time, but facilitates "management" of the intercept altitude, enabling us to achieve intercepts earlier in the midcourse phase. So, as an example, if we launch the ABM at an altitude of 120,000 feet and use the entire 36.26 seconds of C2 time available, the approximate intercept altitude shown in Table 3 is 145,000 feet. If the target were a 100 km-class missile, we would have to find ways to minimize the C2 time required in order to achieve an intercept before the missile reached its apogee of 121,000 feet.

Before we conclude, it seems appropriate to address the likely questions concerning our use of Euclidean geometry without taking into account the curvature of the Earth. In fact, we explored a spherical-Earth model in conjunction with colleagues at AMRDEC, who possess a high-fidelity simulator that deals with this reality. While Euclidean geometry seems an oversimplification of the process, it actually works out to only a fraction of a second difference. One of the primary reasons: using a loitering aircraft mitigates the effects of the earth's curvature.

## **5. Conclusions**

The information presented herein clearly shows that loitering aircraft armed with hypersonic-capable interceptors present an advantageous option for defending against ballistic missiles. The employment of such platforms can yield critical increases in the time available for command and control. We concluded that our loitering aircraft system offers important benefits and merits further exploration. A likely candidate for carrier aircraft is a version of the Air Force's Global Hawk, which can loiter at 60,000 feet for 42 to 72 hours (depending on the payload) (U.S. Air Force, 2005). Even more interesting is ongoing research involving the use of high-altitude airships. A recent Rand technical report describes possibilities the Army is already exploring of manned and unmanned airships capable of loitering for days (even up to a year) at altitudes between 100,000 and

140,000 feet with 100-6000 pound payloads (Jamison, 2005). Such efforts clearly indicate that if we provide engineers with a payload requirement, a minimum altitude, and a loitering time, they could develop a strong capability as an ABM platform.

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The opinions contained herein are the opinions of the authors, and do not necessarily reflect those of AMRDEC, the United States Military Academy, the United States Army, or the Department of Defense.

**7. Descriptors:** Ballistic missile defense, SCRAMJetkinetic energy projectiles, air-based launch, unmanned aircraft,

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